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THE USE OF ONLINE AND OFFLINE PROCESSING TOOLS TO IMPROVE THE PRECISION OF A GPS PASSIVE STATION

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ABSTRACT

Founding of local geodetic points is very crucial for many purposes such as surveying and mapping. In 2011, a control marker was established at the engineering college, University of Duhok (UoD). A survey campaign was carried out to collect GPS raw data of roughly 121 h using Leica Viva GNSS tool at 1-second epoch. The aim was to install an accurate and dependable geodetic point which usually known as the passive station. The accuracy of the established point cannot be reliably checked or compared due to unavailability of any reliable and precise geodetic point near the survey marker. In this paper, investigating the accuracy of that recognized position using the statistical testing is aimed. For that reason, 121 h of raw data was broken into 36 sub-files covering five days of observations, each containing a full of 24 h, 12 h and 6 h of data at 1-second epoch. The data was separately processed utilizing different processing solutions such as free available online PPP services and post processing desktop tool. The aim is to compare the position of each of the subsamples with the most probable value. The results showed that the last recognized and dependable point coordinates are 314075.7788, 4080892.2610, and 525.1899 (m) with RMSE ±3.7, ±3.9, ±6.2 (mm), respectively.

KEYWORDS: Online processing services, GPS, Accuracy, Precise Point Positioning, Gaussian Normal Distribution

1. INTRODUCTION

GPS is a popular utility that provides both military and civilian users with positioning, navigation, and timing services regardless the weather conditions. The free availability of GPS signals' globally and it is accuracy for positioning and timing, in addition to the low cost of receiver chipsets, made the GPS excellent solution for a broad range of civilian applications. Over recent years, the GPS has dramatically increased productivity and resulted in more accurate and reliable data which led to being used dependably by surveying community. To allow rapid and accurate data collection, land surveyors mount GPS rover on vehicles or carry it in a backpack. The rover can communicate wirelessly with reference receivers in order to deliver continuous, real-time, centimetre-level accuracy, and unprecedented productivity (Gps.Gov, 2016).

Reference receiver or station can be set temporarily in a precisely known location or might be a network of stations that running continuously (active station). An example of continuously running stations in Iraq are the network of 7 GPS stations separated all over the Iraq was known as Iraqi Geospatial Reference System (IGRS) (Malkawi, 2011). These stations demand access to the internet, feeding power continually, and restricted in term of monument's structure. A passive station is employed in places where the active station cannot be afforded. The latter is a viable alternative to active stations.

In Great Britain as an example, GPS surveyors precisely position their survey stations in the ETRS89 coordinate system with the help of GPS passive station. Ordnance Survey (OS) built these stations in user-accessible locations as a geodetic quality ground marks. Several OS passive stations within 20-35 km are distributed in a typical survey site all over Great Britain. The remarkable difference between both passive and active station during the data collection is the necessity of occupying passive station by the user's GPS reference receiver. Other main differences are that regular distances from a survey site to the nearest passive stations are smaller than for active stations. Aforementioned allows the use of single-frequency GPS receivers and shorter observation times. In the United Kingdom, all of the passive stations' data can be accessed through ordnance survey website (Ordnance Survey, 2016).

Conventionally, to produce centimetre-level positioning accuracy, at least two geodetic-quality survey receivers required to simultaneously tracking common satellites. Besides, the data demand to be post-processed from static surveys.

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It can also be reached by operating a base station and rover receiver in a Real-Time Kinematic (RTK) mode. The later provides position corrections as the survey is being conducted (Berg & Holliday, 2011). Recently, many of free online processing services have been established to provide the user with a reliable solution. Due to the advancement of these online services, they become a superior tool than the historical methods of control network establishment. Conventional methods included the use of many at least two geodetic dual frequency receivers and antennas. Today, geodetic survey control networks on regional and national scales can be surveyed with only one dual receiver and an online processing service. Using only one receiver and a free post-processing service will help to reduce the personnel, logistics and equipment costs compared to the conventional approach.

The accuracy of these online services have already been evaluated by many scholars (Abd-Elazeem et al., 2011; Alkan et al., 2015; Berg & Holliday, 2011; Ebner & Featherstone, 2008; El-Mowafy, 2013; Farah, 2015; Gandolfi et al., 2016; Grinter & Janssen, 2012; LAHAYE et al., 2008; Tsakiri, 2008). The average accuracies of the online services are found to be in the range of millimeters to decimetres accuracy depending on some factors including the observation time. As a general rule, the coordinate differences are decreases with observing for longer sessions. The precision also varies based on observation type (single or dual frequency). Another important factor is satellite availability. Although the use of Global Navigation Satellite Systems (GNSS) has no significant role in strengthening the accuracy, in urban areas the number of satellite availability is vital for these online services.

Abd-Elazeem et al. (2011) have used Canadian Spatial Reference System- Precise Point Positioning (CSRS-PPP) service (CSRS-PPP, 2016). They evaluate differences in Single frequency static GPS observations at three locations covering time spans of 60, 90 and 120 minutes at different baselines of 1.6, 7, and 10 km, respectively. The finding reveals that the PPP produces a horizontal error at the scale of a few decimetres. Another study by Alkan et al. (2015) investigated the use of GLONASS with GPS to find whether it will help improving the accuracy of PPP. The finding suggested that the use of GLONASS has no significant role in strengthening the accuracy of results. An increase in satellites numbers is vital in urban areas due to the minimum of satellites availability. Using PPP online services, 30 minutes to four hours session were also investigated by Berg and Holliday (2011). With a few exceptions, the coordinate differences were found to be within 10 cm after 30 minutes and 5 cm after 60 minutes. However, there was a remarkable improvement in coordinate comparisons and error estimates after about one hour of data collection.

El-Mowafy (2013) has compared between two of the online engine services (AUSPOS and CSRS). He used four data set of 1 h, 1.5 h, 2 h, and 3 h of length in three different locations. He concluded that AUSPOS have a precision of a few millimeters to a couple of centimeters in the static mode and for the horizontal coordinates. He also concluded that CSRS-PPP processing service can give excellent results at a few millimeters to centimeters. However, a decimetre error was noticed in height component. PPP performance also was evaluated using static positioning with 12 h, 6 h, 3 h, 1 h and 0.5 h observations lengths by Gandolfi et al. (2016) using GIPSY-OASIS II (NASA JPL, 2016). Precision for the 1 h and the 0.5 h observations was found to be between 5 and 10 cm, respectively. Longer observations allow for ambiguity resolution that shows how it significantly improves the accuracy. Grinter and Janssen (2012) used 1 h, 2 h, 4 h, 12 h and 24 h observation datasets with online PPP processing. It was found that at least 4 h last data required to provide a viable alternative to differential techniques for survey accuracy. Ebner and Featherstone (2008) examined a geodetic network solution with 5-day GNSS occupations. Post processing with CSRS-PPP solution showed no significant differences from the scientific Bernese 5.0 solution, later used as a truth data. They also remarked that at least two consecutive days of observations were required to achieve results within 20 mm of the Bernese solution.

In the kinematic mode, the effect of single and dual frequency on PPP online services have also been tested by (Farah, 2015). He used two online processing services, CSRS-PPP and MagicGNSS PPP solution (MagicGNSS, 2016). For dual frequency observations, an error of about 22 mm, 21mm, and 53 mm for latitude and longitude and height components observed, respectively. The single-frequency observations, on the other hand,

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provided poor kinematic PPP solution as the error were in the range of meters, about 3.4m, 2.7m, and 7.5m for latitude, longitude, and height components, respectively. No significant differences were found between both online services (CSRS and MagicGNSS) when dual frequency data used. The errors discovered to be in the range of centimeters and less than 5 cm for all components.

From all related work, it can be noticed that no study considered the use of online services to establish accurate control maker. Except one, all the studies used less than 24 h of observation session. The longer data session will be evaluated in this study. In this research, the aim is to work out a reliable position for the passive station or the UoD survey marker using 5 days of data. To attain high accuracy and to compare the results, three of the post processing online services (CSRS-PPP, AUSPOS, and OPUS) and an offline developed precise point positioning software by a Ph.D. candidate at Nottingham University have been used (Mohammed et al., 2016).

2. ONLINE BASED POST PROCESSING SERVICES

Not too long ago, to position with GPS, it was essential to employ at least two receivers. It was also necessary to post-process the collected data using the GNSS data processing software whether scientific or commercial to obtain accurate results. Nevertheless, the usage of such software is also quite difficult because they require knowledge of the GNSS and experience in the processing, in addition to the cost of the software licensing. GNSS online processing or Internet-based online services are now widely acceptable as an alternative to traditional processing method. The users of these services need to send the collected field data via email or upload it to a particular website. After uploading the data, the coordinates can easily be obtained a few minutes later via user's registered email. It is nowadays possible of data processing for both positioning modes, static and kinematic, via these free online web based processing engines.

Several agencies (NASA JPL, National Geodetic Survey Canada, GMV Innovating Solutions, Geoscience Australia, SOPAC, National Geodetic Survey, and Trimble) have established web services such as (APPS, CSRS-PPP, MagicGNSS, AUSPOS, SCOUT, OPUS, RTX) where dual or single frequency GPS data processing is possible. Some of these services (e.g. AUSPOS, SCOUT, and OPUS) calculate the coordinates with a relative solution or double-differenced phase measurements approach. Others (e.g. CSRS-PPP, MagicGNSS, and APPS) use PPP technique based on the processing from a single GPS receiver employing precise orbit and clock corrections. Most of the online services use International GNSS Services (IGS) orbit products upon availability. The final products are not available until approximately two weeks after the observation day. The rapid orbit product is available two days after observation. If both the final and rapid orbit products are unavailable, then the IGS Ultra-rapid orbit product will be used. Table 1 shows the main characteristic of each web services and spots out some differences.

Table (1): Online Services (APPS, 2016; AUSPOS, 2014; CSRS-PPP, 2016; GMV, 2013; MagicGNSS, 2016; OPUS, 2010; SCOUT, 2011; Trimble, 2016)

Online Services	Processing Technique	Use of Signals	Data Limit max	Acceptable file format	Processing mode	RMSE 24 h
APPS	PPP	Single & Dual	<3.6hrs [a] <7.2hrs [b]	RINEX only	Static & Kinematic [b]	< 1cm
CSRS-PPP	PPP	Single & Dual	<6 d	RINEX only	Static & Kinematic	< 1cm
MAgicGNSS	PPP	Single & Dual	100 MB [c]	RINEX only	Static & Kinematic	Sub-cm
AUSPOS	Relative	Single & Dual	<7 d	RINEX only	Static	< 1cm
SCOUT	Relative	Dual	<1 d	RINEX only	Static	[d]
OPUS	Relative	Dual	<2d	Many	Static	<1 cm [e] <0.5 cm [f]
CenterPoint RTX	-----	Dual	<1d	Many	Static	cm-level

[a] = submit online limit to 5MB of data, using Hatanaka compression and 1second epoch worth about 3.6 h of data.
[b] = Registered User Only. [c]= Limit to 100 MB of data per one file. About 4 days of 1" epoch.

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[d] = High Precision GPS for Earthquake hazards, tectonic plate motion, crustal deformation, and meteorology.
[e]=Vertical RMSE. [f] =Horizontal RMSE.

There are several advantages of these free online services. They can be employed world widely; online positioning services can process data from all over the globe. They can help in decreasing the tools, employees, and overall costs compared to traditional GPS surveying as they offer to operate with a single receiver, typically of dual frequency geodetic-grade type. They are very useful, especially when establishing survey markers or reference stations in remote areas. As mentioned previously, they proved their accuracy, since a single receiver user can obtain accuracy in mm level. Users require collecting data and preferable translating it into the Receiver Independent Exchange (RINEX) format. As most services request, the user usually uploads the data to the processing engine, or the service retains the stored data through a File Transfer Protocol (FTP) link. Shortly after processing the data on the service side, the results send back to the user through an email account.

3. DATA AND EXPERIMENTAL TOOLS

In 2011, the aim was to establish an active station, joining International GNSS Services (IGS) at Duhok University. However, due to some difficulties; continues power feeding and the internet, in addition to survey maker restriction (Monuments restriction), the passive station was preferred. Continuous five days' worth of data has been collected for the point located on the roof of the engineering building, Figure 1. The location was durable, stable and with good satellite visibility. At the time of survey 2011, the building has passed five-year construction. Aforementioned was a minimum requirement recommended by National Geodetic Surveying for the monument selection (NGS, 2013).

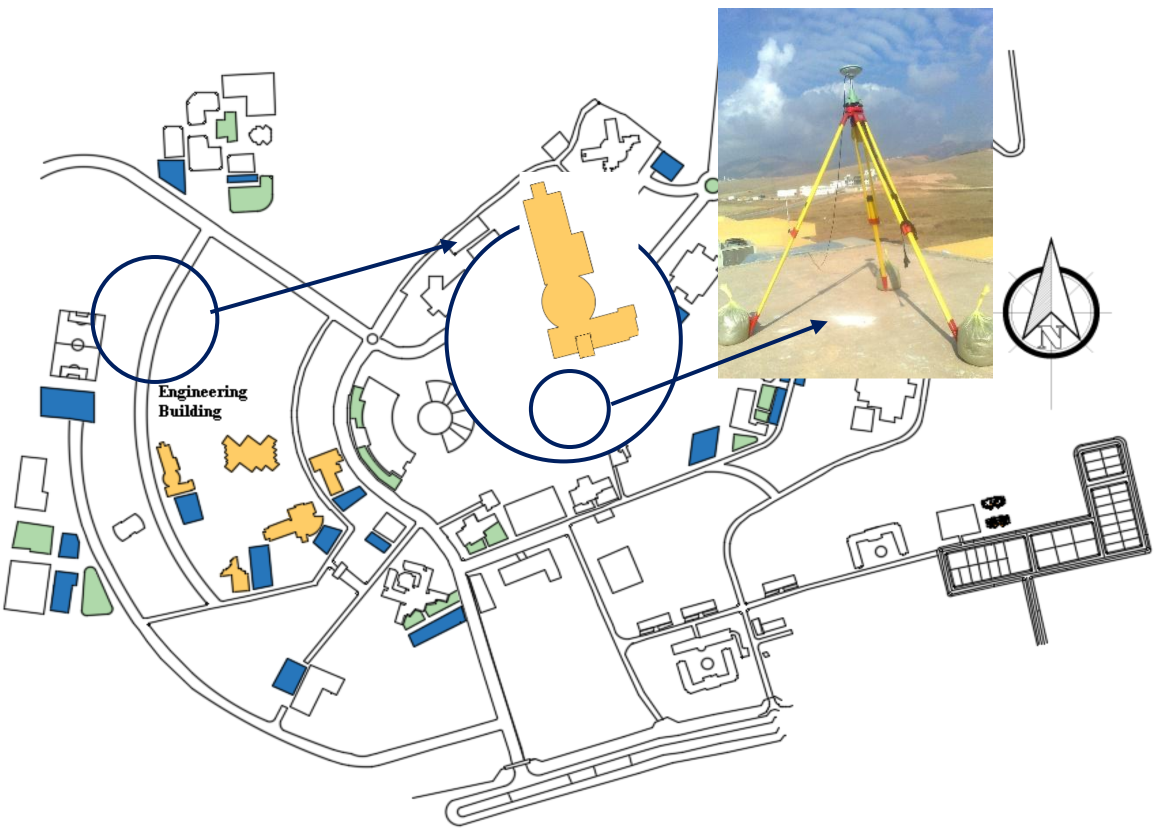

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Fig. (1): Experiment's Location

Data collection was started on 11th of January, 2011 at 9:44:16 and lasted for about 5 days where the last epoch recorded on 16th of January, 2011 at 11:20:08. Translating these dates to the GPS week equal to 1618. 207856 and 1619. 40808 for the start and end observations, respectively. The data worth exactly 5 days, 1 hour, 35 minutes and 52 seconds, collected using Leica Viva GNSS dual frequency with AS10 antenna. These extended observation data will be employed in this study to calculate the most probable value of Easting, Northing, and Height with possible root mean square error for each component. The data processing carried out using the three online post processing services (CSRS-PPP, OPUS, and AUSPOS) along with offline-PPP software.

Pre-processing stage performed on the raw data using TEQC program. TEQC program is a command line tool for translating, editing, and quality check of the GNSS data developed by UNAVCO (Unavco, 2016). In this study, TEQC program was used for translating and time windowing the data. The translation also was applied by TEQC to convert from Leica to RINEX format because most online processing services prefer the RINEX format. Later, the 5 days' data has been time windowed into 24 h, 12 h, and 6 h of data. 36 samples of data were prepared for processing using the online and offline-PPP developed software. RINEX has been compressed to smaller sizes using Hatanaka compression to upload data easier to the web services. Hatanaka compression preferred as files can take as little as 25 to 30% of the space that a standard compression software can offer, for more information refer to (Sopac, 2015).

As previously mentioned, the post processing was carried out using the three online services and offline-PPP developed software. The post processing was carried over a different period. However, all were done over a one month period and with using final IGS product. 143 samples were processed using the 3 online processing services and an offline-PPP software.

4. RESULTS AND DISCUSSION

It has been proved that observing longer will lead to more accurate results. A longer-duration session provides a better opportunity to fix ambiguities and mitigate multipath error accurately. So, before using the post-processing results, a weight has to be assigned to each position resultant according to their observation time. Assigning weights is necessary for statistical testing to be more fair and reliable. Also, all the results were converted to ITRF2008, so the comparison and results are in the same referencing system. For assigning weight to the post-processed results, the model by OPUS was applied. Figure 2 modeled by OPUS shows the relationship between accuracy and session duration (OPUS, 2010). Other formulations (Hayal and Sanli, 2016) for PPP solution were also tested and found slight differences in coefficient compared with OPUS model with very similar weighting outcomes.

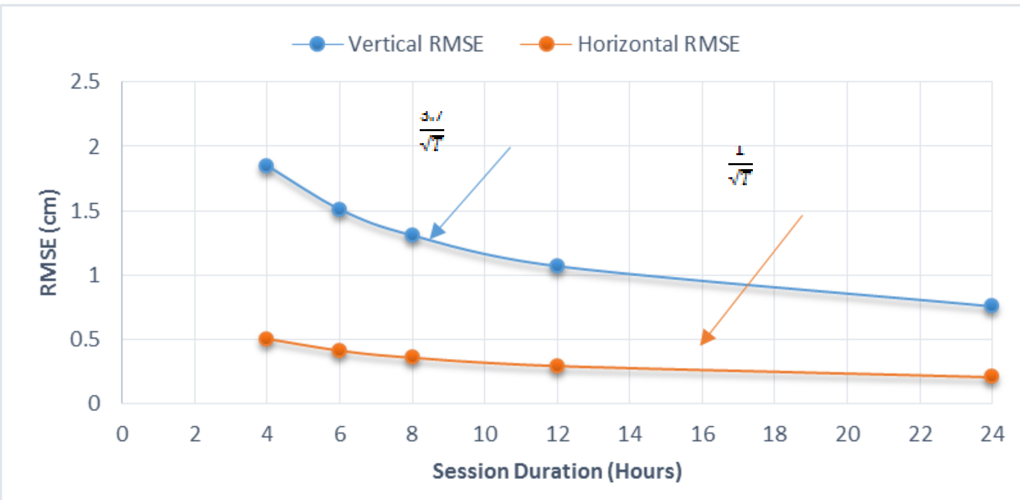

Fig.(2): RMSE versus session duration (OPUS, 2010)

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According to the Figure 2, the RMSE of horizontal components (E and N) is one over the square root of the observation time. For vertical component however, is three and seven tenth over the square root of observation time. From Figure 2, a simple mathematical weighting can be extracted for the horizontal and vertical component. For example, the 6 hours session observation was assigned a one weighting for both vertical and horizontal components. 6 h was minimum observation session used in this study, thus it assigned a one weighing scale. As Figure 2 shows, from 6 hours session to 24 hours, there is an improvement in accuracy to exactly half for both vertical and horizontal RMSE; Table 2 shows the possible weighting values out from the graph and formulas that applied on this study.

Table (2): Weighting Calculated from OPUS accuracy estimation versus observation

Session Duration(hours)	weighting values (Horizontal & Vertical)
6	1
12	1.5 = ~2
24	2
120	4.5 = ~5

After finding appropriate weights, the next step is to calculate the most probable value (mean), the most repeatable measurement (mode) and the median. The mode is most repeatable among different timing solutions, which is a most frequently occurring value in 143 samples. Mode and median only calculated from integer frequencies, therefore, the decimal weighted values were rounded to the nearest integer number as Table 2 shows. Table 3 shows the calculated coordinates and RMSE from the mean, mode, and median.

Table (3): Calculated (Mean, Mode, and Median) with RMS

Coordinates	Easting	Northing	Ellipsoidal Height	3-D RMS
Mean	314075.7786	4080892.264	525.1911	
Mode	314075.7768	4080892.261	525.189	
Median	314075.779	4080892.2609	525.189	
RMSE, equation (1)	±4.2 mm	±3.9 mm	±8.2 mm	±10.0 mm
Average, equation (2)	314075.7781	4080892.2619	525.1897	

Mean: the arithmetic mean of 143 sample with considering the weighting values on Table 2.

Mode: The most frequent or repeatable value from 143 sample with considering the weighting values on Table 2.

Median: denoting or relating to a value or quantity lying at the midpoint of the weighted 143 sample.

The 3-D RMSE calculated from differences of each epoch (143) with the mean value only, equation (3). The RMSE of each component (ENH) are listed in the fourth row of Table 3, and the mean value is shown in the first row of Table 3.

RMSE (σ) = $\mp\sqrt{\frac{\sum_1^n(\mu-O)^2}{n}}$ (1)

Average = (Mean + Mode + Median)/3 (2)

$\sigma ENH = \mp\sqrt{\sigma E^2 + \sigma N^2 + \sigma H^2}$ = 3-D RMSE (3)

Where:

μ=mean   O=observations (samples)   n=number of samples

As Table 3 shows, the mean, mode, and median differences are found to be within ±1 mm of both Easting and Height and ±1.5 mm for Northing component. These fundamental differences could be a good indication of the fact that the solutions are precise and might be free from any outliers. Any of the result shown in Table 3 can be used reliably for all other statistical testing or an average from the mean, mode and median can be calculated and used otherwise. The average of the three values (mean, mode, and median) was employed in this study which was considered to be precise. RMSE reveal that both horizontal and vertical component errors are within about 4 mm and 8mm, respectively. The 3-D RMSE was also calculated and found to be about 10 mm.

The differences between the average shown in Table 3 and each of the 143 observed sample were calculated. Then, the root mean square error (RMSE) of horizontal and vertical components computed from the differences. The process was applied for each session (6 h, 12 h, 24 h, and 120 h) and all services (CSRS-PPP, Offline-PPP, AUSPOS, and OPUS). OPUS cannot process more than 2 days of data processing, thus why 120 h (5 days) only include 3 sets of solutions. The horizontal and vertical RMSE listed in Figure 3.

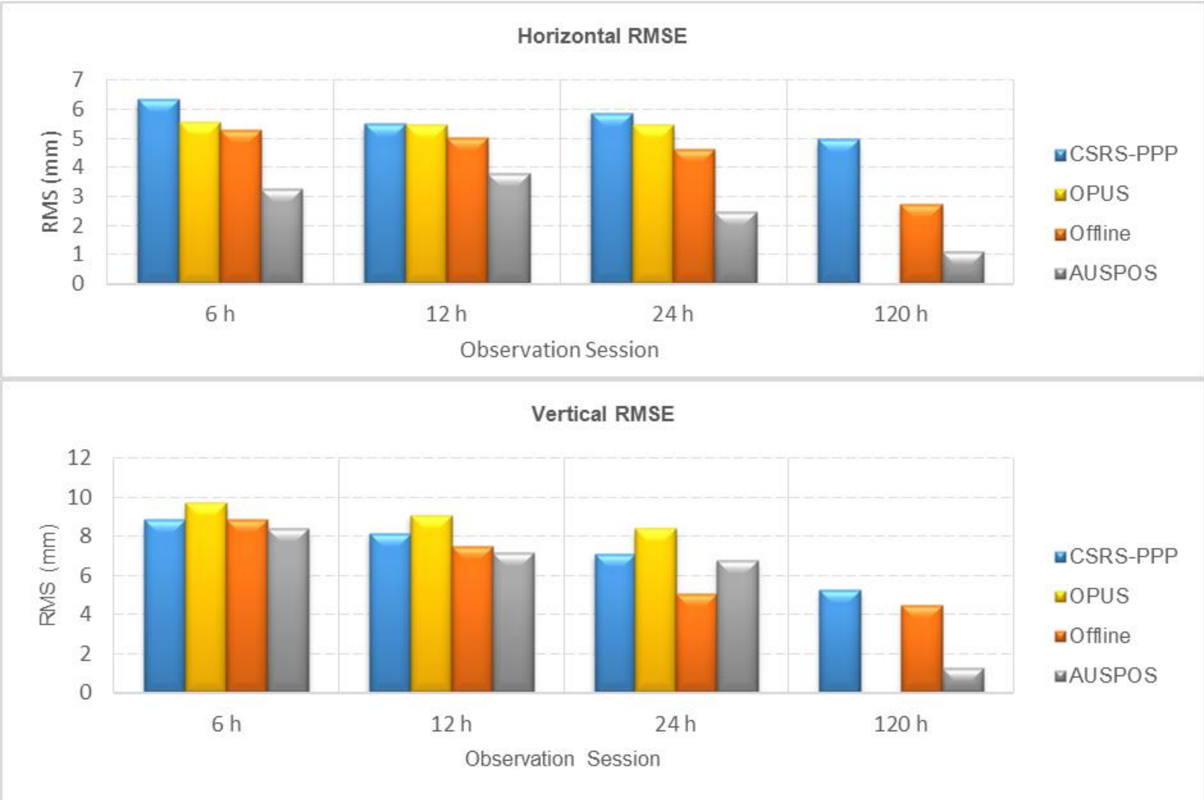

Fig. (3): Horizontal and Vertical RMSE for all services

Figure 3 shows that all the recorded RMSE (horizontal and vertical) and for all used services are less than 1 cm. The observation session does not make any real improvement except within few millimeters if comparing, for example, the 6 hours with 24 hours sessions. The improvement in accuracy is more clearly visible in the vertical component as Figure 3 shows. Comparing services with each other show amazing similarity of results between all of the services processed. They differ only by millimeters demonstrates the robustness of the techniques and processes they use. AUSPOS recorded the minimum results compared with all other services. This finding also confirms the results published by Silver, (2013), as he proved that AUSPOS is outperformed all other online services.

As Figure 3 proved, all the free online and offline-PPP services recorded millimeter accuracy from average value. However, height component errors can reach as high as 30 mm for 6 hours observation sessions, Figure 4. All the maximum errors have been registered for Height component and day 5 exactly. Looking for the historical climate records, it shows that on day 5 there were a continuous raining. This will allow for the wet component error which is up to 10 % to be propagated into the solution. The most mathematical model can accurately predict the dry component which is 90% but cannot estimate the wet component accurately (Navipedia contributors, 2013).

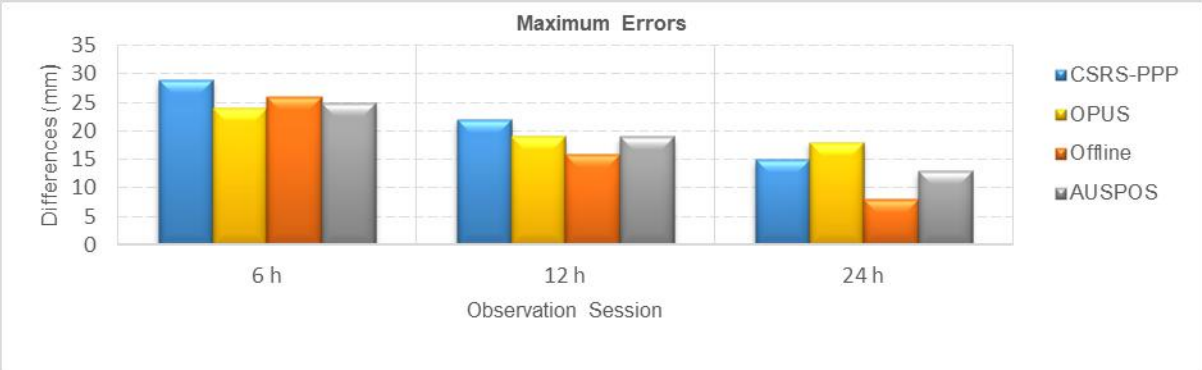

Fig. (4): Maximum recorded error

Generally, the coordinate differences decrease with increasing session length, although there are notable inconsistencies throughout the dataset as figure 4 shows. With a few exceptions, for height component, the maximum error of the coordinate differences are within 25 to 30 mm for 6 hours session and gradually decreases to about 10 to15 mm for 24 h session. As can be seen, there is a remarkable improvement in coordinate comparisons for 24 h data session and all services.

Considering the data analysis with a different perspective may give a better estimation of more reliable solutions. The normal distribution of all the individual samples (143 samples) evaluated including all the services. Histograms with 1 mm bins were created for Easting, Northing, and Ellipsoidal height. Matlab tool was used to draw a Gaussian normal distribution curve, Probability Density Function (PDF), equation (4) which fitted to the data histograms. Then, the data analyzed by looking to those observations locating at the extreme ends of 3 sigma (out of about 99% range) and 2 sigma (out of about 95% range) and the source of services that making these errors. The three histograms (Easting, Northing, and El. Height) with the Gaussian normally distribution fits are shown in Figure 5.

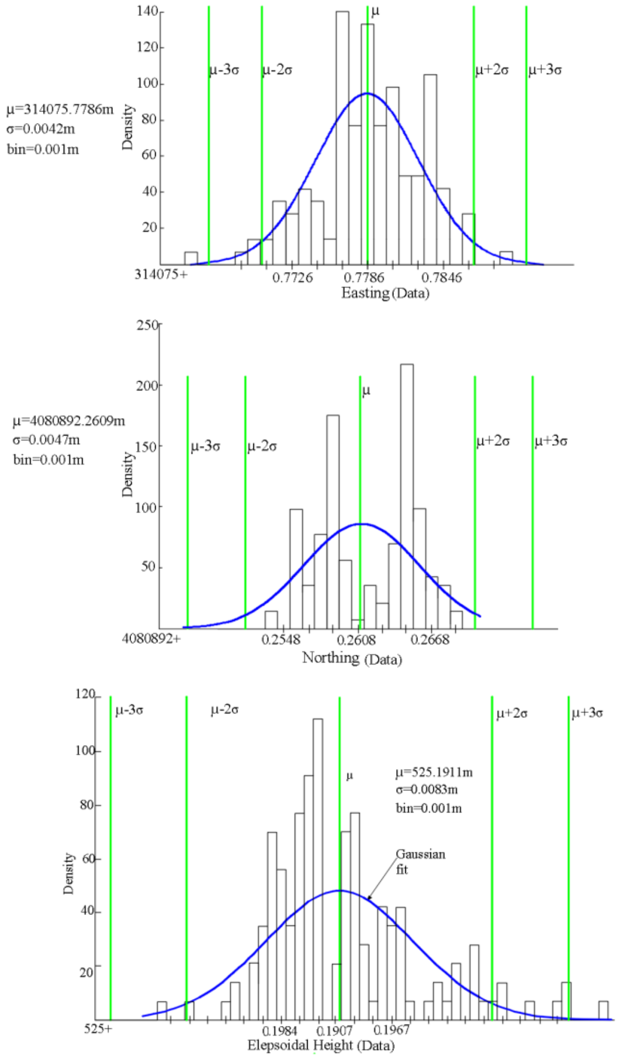

Fig. (5): Easting, Northing, and El. Height Histograms with Gaussian normal fit

Where:
y= density
x= observations The PDF Normal equation $y = f(x|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$ (4)
μ= Mean of observations
σ= Standard deviation (RMSE)

As Figure 5 shows, except for Northing observations, there are outliers at 2 and 3 sigma ranges and for both easting and height components. The outliers for each element and 2, 3 sigma ranges are tabulated in Table 4. Very few outliers were detected for both component easting and height. For east component, only 5 of observations were detected for 2 sigma outlier rejection. All of the 5 outliers' observation except for day02 were for CSRS-PPP online service and day05. The only one outlier is for day02 and was generated from Nottingham's student offline-PPP developed software (Mohammed et al., 2016). However, all of easting outliers were generated from PPP technique (CSRS-PPP and Offline-PPP). Regarding height coordinates, the sum of outliers for 2 and 3 sigma are a total of 10. In contrast to easting observations, all services were found to generate these errors or outliers, most of them about 3 outliers were for CSRS-PPP. To sum up, CSRS-PPP generated more outliers than all other services, 8 in a total of 16 or 50 % of outliers. AUSPOS generated fewer outliers than all other services, 2 in a total of 16 or 10% of outliers. This fact was also addressed by Silver (2013) as he also proved that AUSPOS outperforms other services he tested.

Table (4): Number of outlier counts according to detection range

Detection range	Component	Day02						Day05					
		24h		12h		6h		24h		12h		6h	
		±2σ	±3σ	±2σ	±3σ	±2σ	±3σ	±2σ	±3σ	±2σ	±3σ	±2σ	±3σ
CSRS-PPP	*Easting*							1		1		2	1
	Height									1		1	1
OPUS	*Easting*												
	Height							1		1		1	
AUSPOS	*Easting*												
	Height									1		1	
Offline-PPP	*Easting*					1							
	Height					1						1	

The coordinates of the UoD passive station can be refined further after excluding the 5 % of outliers. The results of outlier rejection, average with RMSE values are listed in Table 05. The difference then can be calculated between these sets of results with those listed in Table 03 which considered as true values. As can be seen, the differences between both results are within less than 1mm. After excluding the outliers as Table revealed, RMSE values became slightly better. So, the final dependable coordinates of UoD control marker can be (314075.7788±3.7 mm, 4080892.261±3.9 mm, 525.1899±6.2 mm) for Easting, Northing, and Ellipsoidal Height respectively.

Table (5): Final Coordinates after excluding outliers

	Coordinates	Easting	Northing	Ellipsoidal Height
5 % Outliers rejection	**Average**	314075.7788	4080892.2610	525.1899
	RMSE	±3.7 mm	±3.9 mm	±6.2 mm
Absolute Differences*		0.7 mm	1 mm	0.2 mm

Absolute Differences = (Average on Table3-Average of 5% outlier rejection Table05)

5. CONCLUSION

Establishing control points is an important for many applications such as surveying and mapping. The accuracy of established control point is not less important than the marker establishment itself. Many of the online services are nowadays available that post-process the raw data to reduce errors and improve accuracy depending on the observation session. The accuracy of these online services has been already evaluated by many researchers around the world.

5 days' worth of data was collected in order to establish a reliable control point at University of Duhok (UoD),. The UoD control marker was post processed using the three online services and the developed offline software by Nottingham University's Ph.D. student. The used tools include both relative and PPP technique. Statistical testing carried out to investigate the accuracy of the established point. The results revealed that the horizontal and vertical RMSE decreases with the increase of observation time. The RMSE for horizontal and vertical component were found to be within less than of about 6mm and 10mm,

respectively for all sessions and processing services. However, significant errors also possible, especially for vertical component. This study proved that less than 1cm accuracy is possible with 6 h data session and an online processing tool. All the online services used in this study provide the final coordinates with a precision of a few millimeters to a maximum error of a couple of centimeters. However, testing is still needed to evaluate the performance in other areas and to include lower observation sessions.

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